A PROPOSED METHOD AND PARTIAL INSTRUMENTATION FOR THE STUDY OF IMPACT STRESSES USING THE PHOTOELASTIC TECHNIQUE.

BY

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A C K N O W L E D G E M E N T

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INTRODUCTION

The progress of technology finds us, today, confronted with an ever-increasing number of technical problems. The automobile, the fast train, the airplane, and a wide variety of high speed machines all require the solution of numerous problems in stress analysis. Among the most important of these problems are those concerned with impact stresses.

Impact stresses are commonly assumed to be those stresses which are applied instantaneously, as by a dropping weight, a sudden jerk on a cable and the like. Quantitatively this is a vague definition indeed, but at present so little is known regarding the effect of the rate of application of load and the rate of propagation of the stresses that for the present at least it will be retained.

Their importance in the design of a structure can easily be seen. A given structure or machine member may be perfectly safe for a certain load, if that load is applied gradually. But the same load, applied instantaneously can and has caused complete failure.

It can also be seen that analysis of these stresses caused by impact is a very difficult matter, because of the exceedingly small period of time during which they act. This period of time can best be measured in millionths of a second, or microseconds. In fact, the only method put forward so far for measureing resistance to impact is the Charpy Impact Test, and this test is almost worthless to the design engineer. In the past he has relied chiefly upon arbitrary rules for computing stresses. These rules have been proved by practice to be safe, though many of them may be uneconomical. They will continue to be used until more accurate methods of measuring impact stresses are devised.

Even with an acceptable understanding of impact upon the resistance of materials there will remain the difficult task of correlating the data obtained in the laboratory under definite strain rates and controlled conditions with the field conditions.

OBJECT

Many difficult problems in stress analysis have in the past been solved by the photoelastic method. Several experimenters have attempted to apply this method to analysis of impact stresses. Several difficulties have combined to prevent complete success so far.

These difficulties are the result of the exceptionally small time interval during which impact stresses act, an interval too short for any known camera shutter.

How would it be possible to obtain photographs of impact stresses?

How can we tell at what instant after impact the photograph has been taken?

The object of this thesis is to answer the above questions, — to develop a method for the analysis of impact stresses.

ANALYSIS

Since no camera shutter is fast enough for our purposes it follows, of course, that our picture of impact stresses must be made without the use of a shutter. So we can place our camera in position with shutter open, darken the room, and then flash our light source at the desired time.

For this plan to work, two conditions must be fulfilled. The light source must give a flash of very small duration, —— fractions of a microsecond. Secondly, the instant at which the photograph is taken must be known and controlled.

Thus it will be possible to obtain a series of pictures showing stress conditions, for example, at 50, 100, 200, 300, 400, and 500 microseconds after the impact load is applied. The load application will have to be repeated for each picture, because the camera will have to be reloaded, and the control circuit reset.

P R O C E D U R E

Load Application

At present it is desired to keep our problem as simple as possible. With this in view we have decided to:

1. Maintain an axial load
2. Apply tensile stresses

A tensile load was chosen because it is a relatively simple matter to reduce bending stresses which may be incident to any load application, to an absolute minimum. With a compressive load applied to a flat specimen such as are commonly used in photoelastic investigations, it would be a difficult matter to prevent any bending or buckling.

There must be some way in which the instant of load application can be determined. Or, in other words, the application of the load must permit the triggering of the electrical control circuit.

There must be some way of measuring the magnitude of the load applied if the results are to be evaluated quantitatively.

The system designed for applying loads fulfills all of these requirements. It consists of an annular weight, with the photoelastic specimen suspended in the center, dropping from above the specimen and striking a round horizontal plate attached to the bottom of the specimen. The weight has four grooves equally spaced on its outer circumference. These grooves fit into four vertical guides.

These guides are part of the frame of the load applying mechanism, and they ensure that the annular weight is in a horizontal position as it strikes the round plate. It follows that if the annular weight strikes the round plate in the manner described, a tensile, axial impact load is placed on the photoelastic specimen.

The striking of the plate by the annular weight is an action which can easily be made to trigger the control circuit, by the closing of an electrical contact.

The weight, before dropping, is held by two spring catches. Its position will be constant for any series of load applications. Hence the distance through which it falls can be accurately measured, and the force of impact computed.

PHOTOELASTIC SPECIMENS

The photoelastic method of stress analysis is based on the effect that the stresses in certain transparent materials have upon a ray of light passed through the member. These materials, when stressed, will resolve an incident polarized light ray into two component rays, one in the direction of each of the principal stresses. Because of the properties of polarized light, a black spot will appear on the projected image of the specimen at every point for which the directions of the principal stresses coincide with the directions of the axes of polarization. Hence the projected image of the beam contains a pattern which shows the distribution of stresses within the member stressed.

M. M. Frocht lists as follows the properties which it is desirable to have in a photoelastic specimen:

1. Transparency
2. Machinability
3. High optical sensitivity
4. Proper hardness
5. Absence of undue optical or mechanical creep
6. Freedom from initial stresses
7. Isotropy
8. Linear stress-strain and linear stress-fringe relations
9. Rigidity
10. Constancy of properties during moderate changes in temperature and treatment
11. Moderate cost

Several kinds of photoelastic material were considered. It was finally decided to use Bakelite BT - 61 - 893. This material is recommended by M. M. Frocht. His book Photoelasticity gives an extensive description of the properties of BT - 61 - 893, and includes several graphs and tables which are useful in determining the variation of these properties under changing conditions. Also, there is much useful information about the dimensions and machining of samples.

A 6" x 14" x $\frac{1}{4}$" sheet of Bakelite BT - 61 - 893 was obtained from the Bakelite Corporation, 300 Madison Avenue, New York 17, New York. These sheets come in a rough finished condition, and must be polished and annealed. For the individual this is a long and tedious job. Fortunately, it will be done by the Polarized Light and Photoelastic Company, 96 Tompkins Circle, Staten Island, New York. The finished dimensions of the Bakelite sheet are approximately $5\frac{1}{2}$" x $12\frac{1}{4}$" x $\frac{1}{4}$".

The apparatus designed will, of course, test specimens of a variety of shapes. The first sample specimen made is as shown in the accompanying sketch.

To assist in machining this specimen, a pair of metal templates, or jigs, were made, of exactly the same dimensions as the specimen, except for thickness.

In making the specimen, the following procedure was used. First a drawing, to exact scale, of the specimen was made, but with one eighth of an inch added to all overall dimensions. The drawing was next trimmed with a pair of scissors, leaving a small margin around the outside lines. Then it was glued securely over the desired part of the Bakelite sheet, using a detachable rubber cement "Grippit".

The sheet is now ready for boring. This operation is done first because it is the most likely to spoil the work. It is recommended that the two holes for the pins be machined by counterboring, as this method is least likely to cause splintering.

The next step is sawing. A new blade should be used in the electric saw in order to minimize the possibility of producing residual stresses. The specimen is sawed along the outside lines of the drawing which is glued over it. Since for this drawing, one-eighth of an inch was added to overall dimensions, the sawed specimen will have a margin of one-sixteenth of an inch over outside dimensions.

Now the specimen is ready to be placed between the templates. Since they are accurately machined, and the two pin holes in the specimen are drilled by eye, an exact fit is improbable. This can easily be remedied,however, by removing a small amount of Bakelite from the inside of one or both holes with a fine triangular file.

With the specimen in the jigs, we are ready for filing to final dimensions. A coarse file will quickly remove most of the extraneous material. Care should be taken not to damage the jigs. Since it is almost impossible to avoid filing the outside edges of the jigs occasionally, the same edges should be kept outside for succeeding specimens. A fine file is used for finishing the edges of the specimen.

Circular files are, of course, necessary for the curved part of the specimen. However, when most of the excess material has been removed, best results were obtained by finishing with the fine triangular file. Special care should be taken at the four corners around the necked down section, as this region will be the most interesting for stress analysis.

The specimen is now ready for testing, which should take place within several hours if possible.

PHOTOGRAPHY

The light source, an electric arc, will of course furnish white light. However, monochromatic light is desirable, to aid stress analysis. Use of monochromatic light is necessary so that the fringe method of stress analysis may be used. With the Magnesium spark in air, W. N. Findley of George Washington University, has found that the Corning Glass Company "Blue Purple Ultra" Number G - 585 M filter (wave length 4481 Å) gives the best result and hence this was selected for the project.

A portrait camera is best for photoelastic work, because it can be focused accurately while the photographer looks through the back of the camera. M. M. Frocht recommends pictures of size 5" x 7". The Rensselaer Polytechnic Institute Physics Department has a 5" x 7" Korona View camera with an exceptionally good lens. This camera is available on loan when needed for the photoelastic work.

The exact intensity of the light source is not known. Therefore it will be impossible to predict in advance the film which should be used. This must be done experimentally. Since the development time also has an appreciable effect on the final result, it too should be determined experimentally.

The following film is recommended as a starting point for the experimental work: Agfa Super Plenachrome Press Film.

LIGHT SOURCE

AND

ELECTRICAL CONTROL CIRCUIT

The problem of photographing the specimen may be considered in two phases:

1. Provide enough intensity of light to effectively expose the film during a sufficiently small time interval to stop the propagation of stress.

2. Control the timing of the light flash to permit the gathering of experimental data which may be used to formulate an expression of stress as a function of the time, or of time rate of strain and also as a function of the distance along the specimen.

At present only one company has developed a lamp which would be suitable to use as a light source. This lamp is the General Electric T - 8 short gap, high pressure, Crypton flash tube. This tube, however, will not be available until about October 1948. The tentative cost of the tube alone is $250.

Since the above flash lamp is not available at present, a method is proposed which will accomplish the same result.

A spark circuit is adaptable to this purpose. As a power source, a condenser is used. The time of discharge of a condenser is a function of the circuit properties, to reduce the time of discharge and hence the duration of the spark to a minimum, it is imperative to reduce the inductance of the circuit to a minimum. The leads from the condenser to the spark gap are therefore kept as short as possible, in fact the spark gap is mounted directly on the condenser terminals.

A mathematical design of this nature is next to impossible since the magnitudes of the electrical properties of inductance, and resistance throughout the entire circuit are indeterminate, hence the design was based entirely upon experimental data furnished by the General Electric Company.

The circuit proposed is composed of 4 units.

1. The Starting Unit
2. The Time Delay Unit
3. The Trigger Unit
4. The Spark Unit

1. THE STARTING UNIT

The Starting Unit consists of a 90 volt D. C. source grounded on one side and feeding through the starting switch into the time delay unit. The starting switch is in fact a means of transmitting a positive voltage pulse into the grid of a tube in the delay circuit at which instant the timing of the cycle begins. It consists of a flat wire glued to the bearing plate of the load application mechanism and insulated from it. The wire has a break in it, thus maintaining an open circuit during all times except at the instant the weight drops on to the bearing plate and closes the contact.

When that gap is closed it signifies the instant of application of force on the specimen.

2. TIME DELAY UNIT

The positive voltage impulse originating in the starting unit actuates the time delay unit. This unit consists of an electronic circuit which is capable of measuring a time interval of from 4 to 250 microseconds. The unit is controlled by means of a resistance and has a calibration dial reading in microseconds delay. Having set the dial on say, 50 microseconds, the delay unit when actuated by the starting unit will send another voltage pulse out exactly 50 microseconds after the starting pulse. This second or delayed pulse is then transmitted into the trigger unit.

3. TRIGGER UNIT

The purpose of the trigger unit is to cause the discharge of the condenser through the spark gap. This is actually the most difficult problem encountered in the entire scheme. Its solution, however, is a relatively simple matter, thanks to an ingenious device developed by Mr. W. R. Plant and patented by the General Electric Company.

The condenser furnishing the discharge energy has across its terminals an exceedingly high resistance (in our case 10 megohms) which is centertapped, thus acting as a voltage divider.

The spark gap itself consists of two primary electrodes and a center probe. Thus the voltage across the two primary electrodes is the full condenser voltage but this voltage is divided into equal parts by the center probe and the voltage appears as one-half the condenser voltage from one primary electrode to the center probe and a half from the center probe to the other primary electrode. This condition is obtained by adjusting the geometric spacing so as to maintain static equilibrium under the impressed voltage (about 2 mm between each electrode and the center probe.)

If by some means we are now able to upset the voltage condition sufficiently, the spark will form across the gaps. A triode is placed across the center probe and the grounded electrode. Under normal conditions this tube (Eimac 250 TL) maintains an open circuit. As soon as a pulse sufficiently large to cause the tube to fire is impressed upon its grid the tube will conduct and effectively short circuit one-half of the resistance in the voltage divider and permit the full condenser voltage to appear across the ungrounded electrode and the center probe and the static conditions will be sufficiently upset to cause the spark to jump from this electrode to the center probe. The current path now will be from one condenser terminal through the spark through the triode back to the other condenser terminal.

There is enough inductance in this circuit to prevent the current from building up as the result of the counter E. M. F. set up in the above-mentioned inductance. Therefore, instantaneously, the center probe will assume the same voltage as the ungrounded electrode since the voltage drop across the spark is negligible compared to the condenser voltage. We have then the full condenser voltage appearing across the center probe and the grounded electrode and the current will follow that path giving a complete short circuit across the condenser through the spark. The speed with which this action takes place is indicated by the time constant (R x C) of the condenser spark circuit which in our case is made sufficiently small to keep the spark time below one microsecond.

The normal procedure for short circuiting one-half the potential divider resistance is by means of an impulse transformer. This method was not used due to difficulty in obtaining the transformer, as well as the matter of economics. It is felt the proposed method is more economical and functionally as sound.

4. SPARK UNIT

A condenser furnishes the spark energy. This condenser is charged by means of a half wave rectifier (tube 8013A) operating at about 15,000 volts. An ordinary neon tube transformer (12,000 volt RMS transformer) is used to step up the line voltage of 115 volts 60 cycle A. C.

Practical problems encountered in the construction and testing.

TIME DELAY UNIT

The circuit is modeled after a multivibrator with an additional tube to isolate the input triode from the final pulse output stage. This has been found to give a better pulse. All the values used have been arrived at by experimental means to give values of time delay from 4 to 250 microseconds.

Originally the circuit was set up on a wood board to facilitate the construction. As presented, the circuit is mounted on an aluminum chassis following the usual methods of radio construction.

HIGH VOLTAGE EQUIPMENT

Great difficulty was experienced in constructing this part of the equipment primarily because of the high voltage involved. The filament transformers for both the rectifiers and the 250 TL triode must be insulated to maintain 15,000 volts. This is essential since the low voltage side of the transformers are grounded and the high voltage side of the spark circuit must for reasons of safety be grounded. In the original circuit which was tested an ordinary filament transformer of sufficient capacity to supply the required amperage was used. The result of testing this circuit under those conditions was disappointing. Since then changes have been made using acceptable means of insulation to take care of the leakage to ground, and although the first test proved that the circuit was practicable, better results are expected when the circuit is in its final form. The type of filament transformer is of a type similar to those used in supplying filament voltages in high voltage magnetrons which are used in radar circuits.

Suggestions for continuation of the project:

Little work was done to determine the optimum shape and spacing of the spark gap electrodes. It is suggested that these values of circuit properties to use be determined by trial and error, as the authors have found little written material covering the subject. The electrode material should, however, be Magnesium. If another material were used difficulty would undoubtedly be encountered in determining the proper filter in obtaining sufficient intensity to successfully expose the film.

RESULTS

Lieutenants Munninger and Burke proved to their satisfaction that the idea for this thesis was practical. Unfortunately, a single semester was far too short to permit carrying the project through to its conclusion as had originally intended.

However, the apparatus to be used was designed, built and tested separately. Numerous difficulties were encountered, especially in obtaining materials of non-standard sizes.

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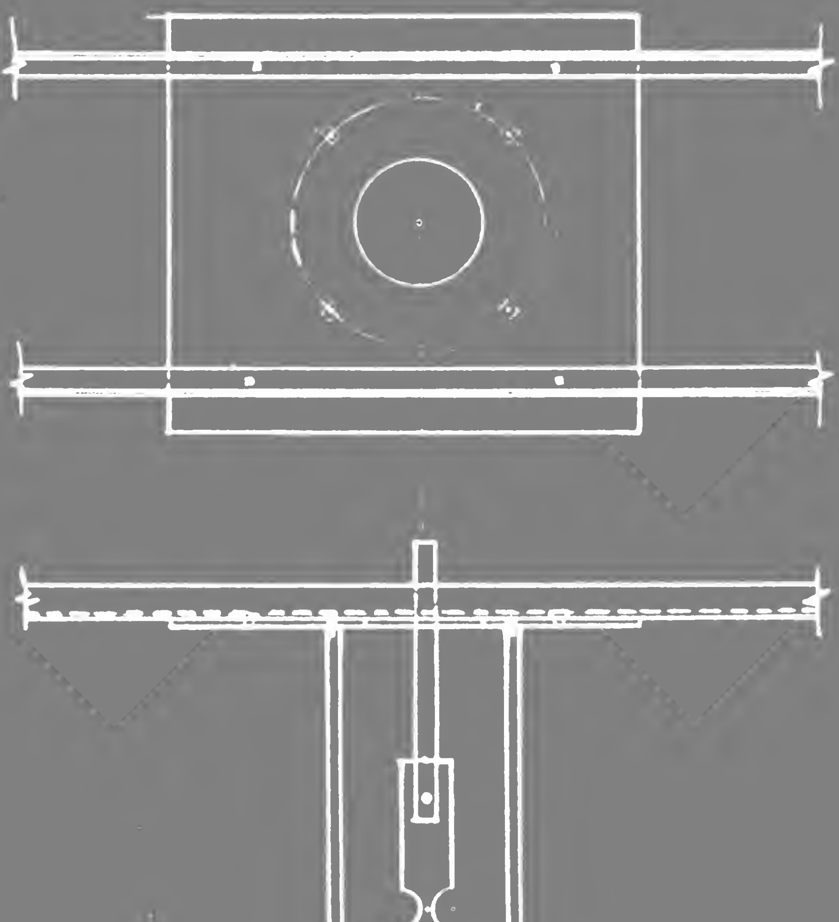
MECHANISM for APPLICATION of IMPACT LOADS



TIME DELAY UNIT